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Pink Bollworm-Gossyplure Studies in the Palo Verde Valley, California

ABSTRACT

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Gossyplure was applied to cottonfields for control of pink bollworm, Pectinophora gossypiella (Saunders), as NoMate PBW or Disrupt, in either case alone or with permethrin (0.004 kg a.i./ha) added to the sticker. Numbers of male moths caught in gossyplure-baited Delta traps in pheromone-treated fields were reduced as compared with those caught in insecticide-treated fields. Number caught increased 5 to 10 days after the last pheromone applications. Percentages of flowers infested, seasonal average numbers of infested immature cotton bolls, and damaged mature bolls were higher in fields treated with Disrupt alone than in fields treated with NoMate PBW or Disrupt plus permethrin, NoMate PBW alone, or insecticides alone. Boll infestations in fields treated with NoMate PBW alone or NoMate PBW or Disrupt plus permethrin were not different than those in fields treated with insecticides alone. Seasonal average numbers of selected beneficial insects were smaller in fields treated with Disrupt or NoMate PBW plus permethrin than in fields treated with Disrupt or NoMate PBW alone. The numbers of male moths caught in traps baited with Disrupt LureTape or NoMate PBW fiber lure were not different when placed in fields treated with NoMate PBW, Disrupt, or insecticides. Further, there were no significant differences in the numbers of male moths caught in traps baited with 1-5 mg of gossyplure in Disrupt LureTape or NoMate PBW fiber lures. The standard deviations of male moth catches in Delta traps decreased when more then 25 were caught per trap/night, indicating the upper level of efficiency of the trap. The calculated 95-percent confidence limits for 1-10 traps per cottonfield at different moth population densities showed that a minimum of 4 traps per field were required to obtain meaningful estimates of the average trap per night catch.

KEYWORDS: beneficial insects; cotton; gossyplure; insecticides; Palo Verde Valley, California; Pectinophora gossypiella; pheromones; pink bollworm; traps

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PINK BOLLWORM-GOSSYPLURE STUDIES IN THE PALO VERDE VALLEY, CALIFORNIA

by C.A. Beasley and T.J. Henneberry[1]

INTRODUCTION

The pink bollworm, Pectinophora gossypiella (Saunders)(Lepidoptera:Gelichiidae), has been a major pest in the southwestern desert cotton-producing areas of Arizona and California since 1965. Suppression of this pest has been achieved through heavy reliance on insecticides. The need to reduce excessive control costs, as well as adverse effects of scheduled insecticide applications, has stimulated much research to develop alternative control technology.

The pink bollworm sex pheromone was identified in 1973 as a 1:1 ratio of Z,Z- and Z,E-isomers of 7,11-hexadecadienyl acetate and named "gossyplure" (Hummel et al. 1973). Since that time, extensive studies have been conducted to determine the potential of the pheromone as an integrated pest management tool in cotton production systems. Promising research results, indicating the potential of gossyplure for behavioral control of pink bollworm by mating disruption (Shorey et al. 1974, Gaston et al. 1977), resulted in the development of controlled release gossyplure carrier systems for use in commercial cottonfields.

At present, two slow-release systems for gossyplure are commercially available: (1) NoMate PBW (Albany International Co., Needham, MA; gossyplure contained in 1.5-cm-long, polyacetal resin hollow fibers) and (2) Disrupt (Hercon Division, Health Chem Corporation, New York, NY; gossyplure contained in the middle layer of a 0.3-cm^2, three-layer plastic-laminate system). NoMate PBW fibers suspended in Bio-Tac and Disrupt flakes suspended in Phero-Tac are aerially applied using special equipment designed by the respective manufacturers (Funkhouser 1979, Kydonieus et al. 1982). Promising results have been reported with commercial applications of NoMate PBW (Brooks and Kitterman 1977, Brooks et al. 1979, Doane and Brooks 1981) and Disrupt (Butler et al. 1983), using mating disruption, as compared with scheduled insecticide applications for early season pink bollworm control.

Staten and Haworth (1981) suggested the addition of small amounts of pyrethroid insecticide to the NoMate PBW sticker (Bio-Tac) to kill male pink bollworm moths attracted to and contacting individual point sources of hollow fibers or sticker droplets.

Gossyplure has also been used extensively as a bait in traps for survey and detection (Foster et al. 1977) and as part of a monitoring technique to determine the need for control action and evaluate the effectiveness of the treatments in suppressing pink bollworm populations (Toscano et al. 1979).

In cooperation with growers and pest-control advisers in California's Palo Verde Valley, we evaluated pink bollworm behavioral control in 1982 by comparing male moth catches in gossyplure-baited traps and infestations in blooms and bolls. We also studied the effects of pheromone treatments with or without the insecticide permethrin

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[(3-phenoxyphenyl)methyl 3-(2,2-dichloroethenyl)-2,2-dimethylcyclopropanecarboxylate]on the numbers of selected beneficial predators in 1982 and 1983. Fields were treated commercially with (1) Disrupt with and without permethrin in Phero-Tac, (2) NoMate PBW with and without permethrin in Bio-Tac, and (3) insecticides only. Further, since data obtained from gossyplure-baited traps in cottonfields are heavily relied on as a measure of relative pink bollworm moth population densities, there was a need to evaluate pheromone-baited trap systems. Thus, in 1982 we also conducted concurrent trapping studies to evaluate trapping methods and set confidence limits on data obtained for various numbers of traps needed per field to accurately estimate the numbers of moths caught at different population densities. This paper is a report of these studies.

METHODS AND MATERIALS

Behavioral Control and Beneficial Insects

Six cottonfields (59 to 163 ha each) were aerially treated with NoMate PBW or Disrupt, in either case with or without permethrin added to the respective stickers, for a total of 24 fields. Treatments indicated as NoMate PBW(+) and Disrupt(+) had permethrin added to the stickers, and NoMate PBW(-) and Disrupt(-) were applied without added permethrin. The amount of added permethrin was about 0.004 kg a.i./ha. Gossyplure, as NoMate PBW and Disrupt with or without permethrin, was applied at the rate of about 2.86 g a.i./ha (37.1 g product/ha) and 3.71 g a.i./ha (148.2 g product/ha), respectively. Pheromone treatments in all fields were initiated about the time of occurrence of first flowers. Six fields (49 to 140 ha each), treated with insecticides for pink bollworm and/or other insects, were selected as controls.

Planting (first irrigation) dates for 27 of the experimental fields were from March 13 to April 13. Three fields were planted and irrigated on April 29, May 6, and May 8.

Effect of the treatments on male moth trap catches was determined from the end of May through the first week in September by installing one Delta trap (Sandia Die and Cartridge Co., Albuquerque, NM), baited with a Hercon LureTape (1.3 cm^2), in each quadrant of each experimental field. Baits were changed monthly. Traps were free swinging and attached, at canopy height, to bamboo stakes by cotton strings.

Traps were checked twice a week, at which times male moths were removed from the traps and their numbers recorded. Traps were replaced when 50 moths had been caught or when that number was expected to be exceeded by the next trap-checking date. No trap was located closer than 30 m to a field edge and during concurrent trap studies, other traps in field quadrants were not closer to each other than 45 m. Traps knocked down by wind or field equipment were considered as nonreporting during that trap period (average of 3 percent during the season). Estimates were made for one or two nonreporting traps in a field by using the average of moths caught in the other reporting traps. When three or four traps failed to report in a single field, data for that period for that field were considered as missing.

Early season pink bollworm infestations were sampled by counting, twice weekly, the numbers of infested flowers and total white flowers along 30 m of randomly selected rows at least 30 m from field edges in each field quadrant of each experimental field. Fields were treated with Disrupt and NoMate PBW an average of 13.7 and 6.5 days, respectively, before the first flower counts. Flower counts were initiated in fields treated with insecticides an average of 9.7 days before the first trichlorfon [dimethyl(2,2,2-trichloro-1-hydroxyethyl)phosphonate] treatment. Counts were made from about 15 through 50 percent flowering. Sampling for

infested flowers was terminated when adequate samples of susceptible cotton bolls were available. Susceptible bolls (25 bolls, 14 to 21 days postanthesis) were collected at random from each field quadrant and at least 30 m inside field edges.

The bolls collected in each field were combined and stored outside in the shade in ventilated plastic boxes (Fye 1976) for 14 days. The numbers of adult moths, pupae, and larvae in each box were counted. All bolls in each box were then opened and examined for pupae and larvae. During the last week in August to mid-September, the numbers of damaged, mature, open bolls in 250 bolls examined were determined for all quadrants of all 30 fields. Damage to open, mature cotton bolls was considered to be the presence of exit holes, holes in the interlocular septa, damage to seed, or the presence of mold in the open cotton associated with pink bollworm damage. Plants were selected at random, and the number of bolls examined per plant varied from about four to six.

In 1982, effects of the gossyplure with and without permethrin and of insecticide treatments on beneficial insect predators were determined by taking 100 sweeps twice weekly with a standard sweep net in each field quadrant. Contents of the net from each 100 sweeps were transferred directly to labeled 473-mL glass jars containing about 50 mL of 85 percent ethyl alcohol. Adults and immature forms of *Orius*, *Nabis*, *Geocoris*, *Chrysopa*, and Reduviidae and adults of *Collops*, Coccinellidae, and spiders were counted and recorded. Sweep net sampling was begun in pheromone-treated fields within 8 days after the first applications (June 4-14) and in trichlorfon-treated fields 23 days before the first application (July 1). Each field was sampled twice a week thereafter through the end of July. Similar studies were conducted in 1983 except that 200 sweeps per field quadrant were taken in fields treated only with NoMate PBW alone and with NoMate PBW plus permethrin. Also, pretreatment (the day of pheromone treatment with or without permethrin application) counts were compared with posttreatment counts taken 48 h after application.

Trap Studies

Two Delta traps per quadrant were installed in each of four of the cottonfields treated with NoMate PBW, Disrupt, or insecticides. The effect of the treatments on male moth catches in traps baited with NoMate PBW fibers or Disrupt LureTape was determined by baiting one trap in each quadrant with a Disrupt LureTape (1.3 cm^2, about 2 mg gossyplure) and the second trap with a NoMate PBW fiber lure (10 fibers, about 2.3 mg gossyplure). Traps were set in the fields on June 16 and checked twice weekly through July 13, 1982. Numbers of male pink bollworm moths were recorded on each sampling date.

The effect of amount of gossyplure bait used was determined by baiting traps with one-half, one, or two Disrupt LureTapes (about 1, 2, or 4 mg gossyplure, respectively) or 5, 10, or 20 NoMate PBW fibers (about 1.2, 2.3, or 4.6 mg gossyplure, respectively). Traps in each case were placed in each quadrant of cottonfields treated with NoMate PBW, Disrupt, or insecticides only. Traps were set in the fields on July 26 and checked twice weekly through August 9, 1983.

Estimates of the number of traps per field needed to accurately sample the male moth population were determined by using all data from traps (baited with Disrupt LureTape--1.3 cm^2, about 2 mg gossyplure) set in the field the last week in May and monitored twice a week through the first week in September. About 3,350 trap readings were made in the study and were used to calculate the standard deviations associated with trap catches at various male moth population densities and establish confidence limits for use in estimating the number of gossyplure-baited traps per field needed to describe the male moth population within the average variability of trap catches.

STATISTICAL ANALYSIS

Behavioral Control and Beneficial Insects

Growers and pest-control advisers, in consort with representatives of the pheromone companies, made all decisions regarding initiation, frequency of application, and time of termination of pheromone and insecticide treatments. For convenience and economy, several fields within some treatment regimes were often block-treated (for example, two to four contiguous fields out of six for some of the treatment regimes were often aerially treated across rows without interruption). This arrangement negated a completely randomized design; however, for the purposes of analyses, we assumed that fields were randomized within treatments. Thus, unless otherwise stated, the basic analysis was a one-way analysis of variance with five treatments: NoMate PBW(+), NoMate PBW(-), Disrupt(+), Disrupt(-), and insecticides only. Six fields within each treatment served as replications. Some analyses also included quadrants as a split-plot factor.

In order to remove time as a source of variation in the analyses, data were averaged over sampling dates; however, to examine seasonal changes in parameters monitored, certain data were plotted against time. Analyses were performed on data sets where no estimates for missing values were included and on those where estimated values were included. Also, data were analyzed after transformations were performed for both data sets. Minor differences in mean values were noted between analyses; however, neither ranking of means nor their significant differences changed as a result of including estimated values or data transformations.

In 1982, effects of including permethrin with the sticker for the gossyplure-controlled release systems were examined and statistically analyzed using a subset of data in which numbers of beneficial predators collected in sweep nets were included only from the beginning of the pheromone application for each field to 10 days following the last pheromone application. If an insecticide application was made before the last pheromone-treatment date, numbers of beneficial predators in sweep samples were not included beyond that date. The results were compared with the numbers of beneficial predators collected in sweep samples in trichlorfon-treated fields. In 1983, the effects of permethrin in the sticker of NoMate PBW applications vs. NoMate PBW alone on beneficial insects were compared using the pretreatment and posttreatment counts in a split plot in time analyses of variance.

Trap Studies

The analysis of variance performed on the average number of male moths per trap/night caught in the bait-type studies was a split-split plot in a completely randomized experimental design. Field treatments (NoMate PBW, Disrupt, and insecticides) were main plots, fields were replications, quadrants were the first subplot, and bait types were the second subplot.

The analysis of variance on average numbers of male moths caught per trap/night in traps baited with different amounts of each bait was a split plot in a completely randomized experimental design. Treatments (fields treated with NoMate PBW, Disrupt, and insecticides) were main plots (one field of each), quadrants within fields were replicates, and the six combinations of lure type (NoMate PBW and Disrupt) with lure amounts were subplots.

The 95-percent confidence intervals for average numbers of male moths per trap/night, when we used various numbers of traps per field, were calculated by obtaining an estimate of the standard deviation (s.d.) between traps in all fields using standard statistical methods. A scatter-plot diagram of the calculated standard

deviations between trap counts in each field vs. average counts was prepared to determine the need for data transformation. Later, the male moth trap counts were all transformed to log (count +1) and the standard deviations recalculated.

For the average log (count +1) <1.4, a straight line was fitted for standard deviation vs. average moth trap catch. The equation obtained was s.d.= (0.13933)+(0.12884 x average). Using the estimate of standard deviation, 95-percent confidence intervals were calculated by

$$\overline{X} + \frac{2\ (\text{s.d.})}{\sqrt{\eta}}$$

in log scale and were then converted to male moth counts.

Mean differences for behavioral control, beneficial insects, and trap data, where appropriate, were separated using Duncan's multiple-range test (Duncan 1955).

RESULTS

Behavioral Control and Beneficial Insects—Pheromone and Insecticide Treatments

The average numbers of NoMate PBW(+) and NoMate PBW(-) applications per field in each case were 3.5 and 4.7, respectively, between June 6 and August 5 (table 1). Trichlorfon was applied an average of 1.3 times to NoMate PBW(+) and 0.7 times to NoMate PBW(-) fields during the same period. The last application of NoMate PBW(+) was made on August 5 and NoMate PBW(-) on July 30. For the season, an average of 9.0 and 9.2 insecticide applications were made to fields treated with NoMate PBW(+) and NoMate PBW(-), respectively. The average numbers of Disrupt(+) and Disrupt(-) applications per field were 5.0 and 4.7, respectively, between June 4 and July 24 (table 1). All fields treated with Disrupt(-) were also treated once with trichlorfon and sulfur, and four of the six fields were also treated with permethrin within a week before the last Disrupt(-) application. Two of the fields treated with

Table 1. Average[1] numbers of treatments, gossyplure formulations plus and minus permethrin in the stickers, and insecticides in all pink bollworm suppression programs

	Numbers of--		
Pink bollworm treatment	Pheromone treatments	Insecticide treatments	Total
NoMate PBW(+)	3.5	9.0	12.5
NoMate PBW(-)	4.7	9.2	13.9
Disrupt(+)	5.0	6.7	11.7
Disrupt(-)	4.7	8.7	13.4
Insecticides	none	12.8	12.8

[1]Averages of 6 cottonfields.

permethrin did not receive the fifth application of Disrupt(-) on July 24. Last applications of Disrupt(+) to all six fields were made on July 24.

Despite differences in cotton planting times and sampling for infested flowers, the availability of susceptible bolls matched well with phenological crop development, as determined by field observations and model projections based on heat-unit calculations.

Effects on Male Pink Bollworm Moth Trap Catches

Before initial treatments, gossyplure-baited traps caught significantly greater numbers of male pink bollworm moths in fields scheduled for Disrupt applications than in fields scheduled for NoMate PBW or insecticide applications (table 2).

Male moth catches declined to an average of less than one per trap/night in Disrupt and NoMate PBW-treated fields during the periods pheromones were applied (fig. 1). The first fields were treated on June 4. Figure 1 includes data for pheromone-treated fields from the first trap records after the first pheromone applications to 10 days after the last pheromone applications or to the time when an insecticide was applied to the field, whichever came first. For insecticide control fields, trap data in figure 1

Table 2. Average[1] percentages of pink bollworm-infested flowers[2] and average numbers of male pink bollworm moths caught in cottonfields treated with NoMate PBW, Disrupt (in either case with (+) and without (-) permethrin), and insecticides

Pink bollworm treatment	Infested flowers (%)	Male moths per trap per night		
		Before	During	After
		(pheromone applications)[3]		
NoMate PBW(+)	0.1b	1.7c	0.4b	3.4c
NoMate PBW(-)	.1b	1.4c	.3b	5.8c
Disrupt(+)	.3b	3.8b	.6b	18.0b
Disrupt(-)	.6a	6.8a	.7b	25.1a
Insecticides	.1b	2.6bc	2.7a	20.0b

[1]Averages of 6 replications. Averages in the same column not followed by the same letter are significantly different according to Duncan's multiple-range test, $\underline{P}$=0.05.

[2]Twice weekly from about 15 to 50 percent bloom (June 10 to July 22, 1982).

[3]Before = 3 sampling dates, May 28 to June 4; during = various sampling dates within the time pheromone-only applications were utilized or during the time when only trichlorfon treatments were utilized for insecticide-only fields; after = 9 sampling dates, August 10 to September 8.

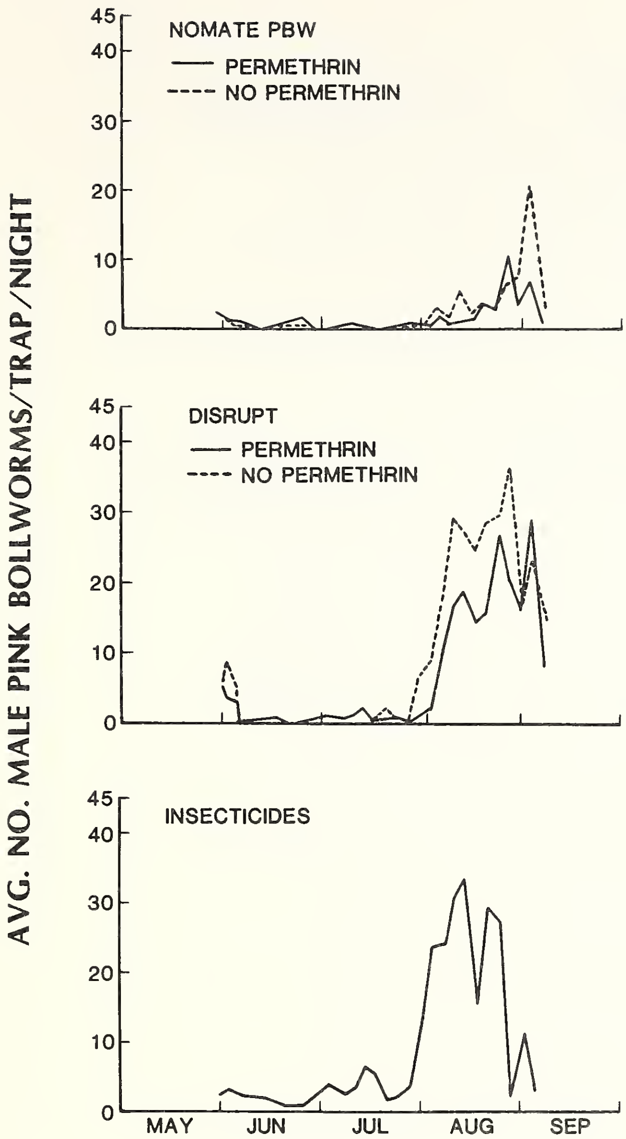


Figure 1.
Average numbers of male pink bollworm moths per trap/night in six fields treated with NoMate PBW with and without permethrin in Bio-Tac, Disrupt with and without permethrin in Phero-Tac, and insecticides only.

are included up to the time when an insecticide other than trichlorfon was applied.

Significantly higher numbers of male pink bollworm moths were caught between June 6 and August 5 in fields treated with insecticides than in fields treated with Disrupt or NoMate PBW, in either case with or without permethrin (table 2). Trap catches were not significantly different in fields treated with Disrupt or NoMate PBW with or without permethrin. From August 10 through September 8, male moth trap catches were significantly higher in fields that had been previously treated with Disrupt than in fields treated with NoMate PBW (table 2).

Infested Flowers

During the period of 15-50 percent flowering, the percentage of infested flowers was significantly higher in fields treated with Disrupt(-) than in fields treated with Disrupt(+), NoMate PBW(+), NoMate PBW(-), or insecticides (table 2). Since three of the six NoMate PBW(+)-treated fields were planted 40-48 days (April 29, May 6, and May 8) later than the other three fields, percentages of infested flowers counted from 15-50 percent of the flowering period were compared (one-way analysis of variance with quadrants as a split-plot factor) separately for those two sets of three fields. There was no significant difference between the numbers of infested flowers in early vs. late-planted fields treated with NoMate PBW(+).

Infested, Immature, and Damaged Open Bolls

The seasonal average numbers of pink bollworms (adults, pupae, and larvae) per 100 immature bolls showed results similar to those for percentages of mature open bolls damaged (table 3). Fields treated with Disrupt(-) had a significantly higher percentage of mature, open boll damage than did fields treated with Disrupt(+), and fields treated with either Disrupt(+) or Disrupt(-) had significantly higher percentages of mature, open boll damage than did fields treated with insecticides or NoMate PBW with or without permethrin (table 3). The ranking of means for percentages of mature, open boll damage and the percentages of immature infested bolls, as compared with values for all life stages per 100 bolls, indicate that boll samples from fields with the greatest percentage of

Table 3. Average seasonal percentages of pink bollworm-infested, immature[1] bolls, average seasonal number of pink bollworms per 100 bolls,[2] and average percentages of pink bollworm-damaged, open[3] bolls in cottonfields treated with NoMate PBW, Disrupt (in either case with (+) and without (-) permethrin), and insecticides

Pink bollworm treatment	Immature bolls: Infested (%)	Immature bolls: Pink bollworms/ 100 bolls (No.)	Mature open bolls damaged (%)
NoMate PBW(+)	2.5c	2.3b	1.0c
NoMate PBW(-)	3.0c	3.3b	1.2c
Disrupt(+)	5.6b	6.1b	4.5b
Disrupt(-)	10.8a	14.6a	10.5a
Insecticides	3.8bc	4.0b	1.8c

[1]Averages of 6 replications, twice weekly samples of 100 bolls/field from June 28 to September 1. Averages in the same column not followed by the same letter are significantly different, according to Duncan's multiple-range test, P=0.05.

[2]Average number of the sum of adults, larvae, and pupae/100 bolls.

[3]Average of 6 replications, 1,000 bolls per replication. Sampled between August 24 and September 16.

infested immature bolls and mature, open boll damage also had the highest numbers of larvae per boll. Although one pink bollworm larva can develop through all of its instars within one seed, the number of seeds damaged per pink bollworm, as determined from averages over all treatments, over all dates, was 4.5.

The average numbers of pink bollworm (adults, pupae, and larvae) per 100 immature bolls for each sampling date are shown in figure 2. The data plotted separately for the three late- and three early planted fields treated with NoMate PBW(+) show that the late-planted fields had lower boll infestations than the earlier planted fields and the six fields treated with NoMate PBW(-). Late-planted fields did not have susceptible bolls until after mid-July.

Effects on Beneficial Insect Predators

In 1982, numbers of individual predator species on each sampling date varied but were generally lower in fields treated with gossyplure plus added permethrin as compared with fields treated with gossyplure alone, except for Reduviidae and spiders (fig. 3).

The seasonal average numbers of individual predator species (both adults and immatures where appropriate) showed that numbers of spiders and Reduviidae

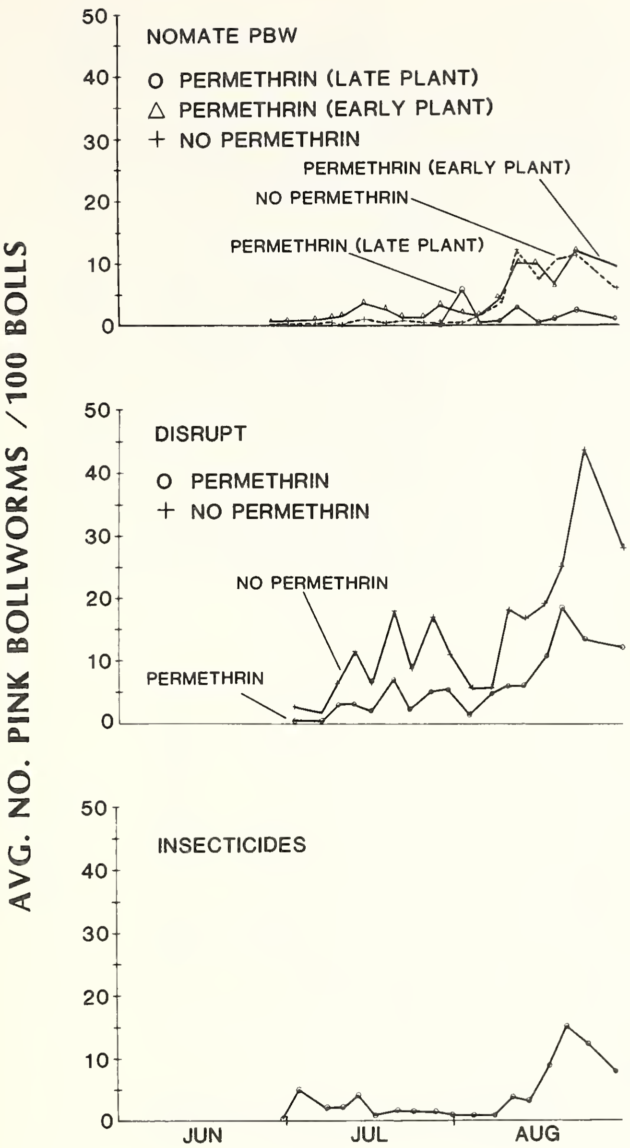


Figure 2.
Average number of pink bollworms (adults, pupae, and larvae) per 100 bolls in six fields treated with NoMate PBW with and without permethrin in Bio-Tac, Disrupt with and without permethrin in Phero-Tac, and insecticides only.

were not significantly different in fields treated with NoMate PBW(+) and Disrupt(+) as compared with fields treated with NoMate PBW(-) and Disrupt(-) (table 4). Numbers of Geocoris were not decreased by including permethrin with NoMate PBW [as compared with NoMate PBW(-)] but were significantly less in fields treated with Disrupt(+) as compared with fields treated with Disrupt(-). Numbers of Orius, Nabis, Chrysopa, Collops, and Coccinellidae were significantly lower in fields treated with Disrupt(+) or NoMate PBW(+) than for fields treated with Disrupt(-) or NoMate PBW(-). Seasonal total average numbers of Orius, Nabis, Geocoris, Chrysopa, Collops plus Coccinellidae, sampled in fields treated with Disrupt(+) (12.6c) and NoMate PBW(+) (12.6c), were significantly different from those sampled in fields treated with Disrupt(-) (22.1a), NoMate PBW(-) (17.6b), or insecticides (18.3b). Seasonal total average means of the six taxa listed followed by the same letter are not significantly different.

In 1983, the numbers of beneficial insects sampled were lower than occurred in 1982 (table 4). The pretreatment and posttreatment numbers of each species sampled in NoMate PBW fields alone and NoMate PBW plus permethrin fields were analyzed separately. The results showed an adverse impact of the added permethrin on all species except Geocoris, but the differences were not statistically significant. When the total numbers of Orius, Nabis, Chrysopa, Collops, Coccinellidae, and spiders were combined for analyses, the pretreatment samples (21.9b) were significantly smaller than the posttreatment samples (30.9a) in NoMate PBW fields. Conversely, the total numbers in the posttreatment samples (19.9b) were significantly smaller than in the pretreatment samples (27.5a) in fields treated with NoMate PBW plus permethrin. Average numbers of each of the 8 beneficial predators (adults and immatures where appropriate) counted each week in all 30 fields in 1982 are shown in figure 4. Low numbers of immature Orius, Nabis, and Chrysopa were collected in sweep net samples (fig. 4).

Numbers of adult Orius and Geocoris were consistently high through July and showed evidence of two generations (fig. 4). Numbers of Geocoris declined significantly in early August. Numbers of adult Nabis steadily decreased

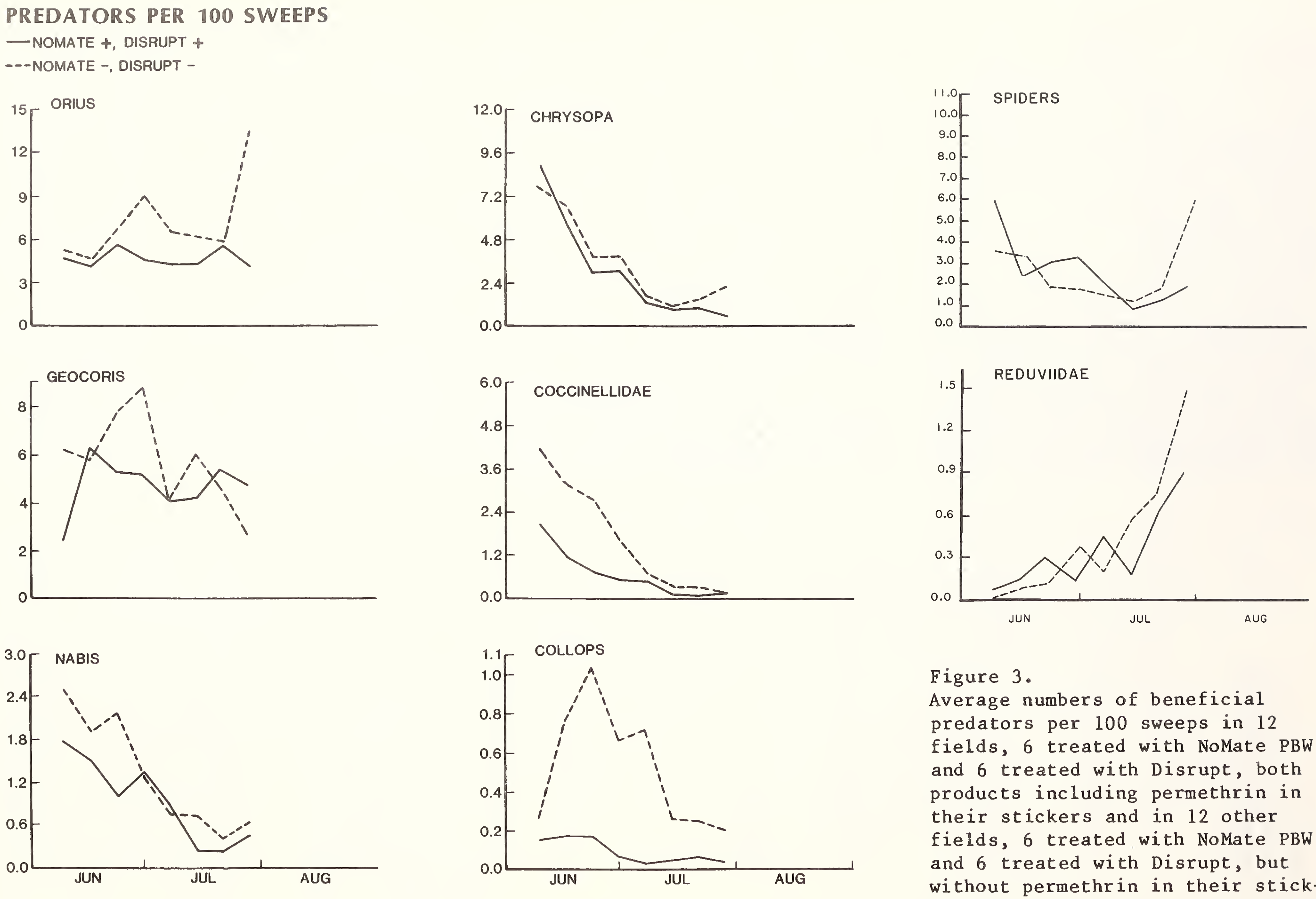


Figure 3.
Average numbers of beneficial predators per 100 sweeps in 12 fields, 6 treated with NoMate PBW and 6 treated with Disrupt, both products including permethrin in their stickers and in 12 other fields, 6 treated with NoMate PBW and 6 treated with Disrupt, but without permethrin in their stickers. Numbers were excluded from the averages beyond the date when any insecticide was applied to a field.

Table 4. Average[1] number of beneficial predators in cottonfields treated with NoMate PBW or Disrupt, in either case with (+) or without (-) permethrin or insecticides

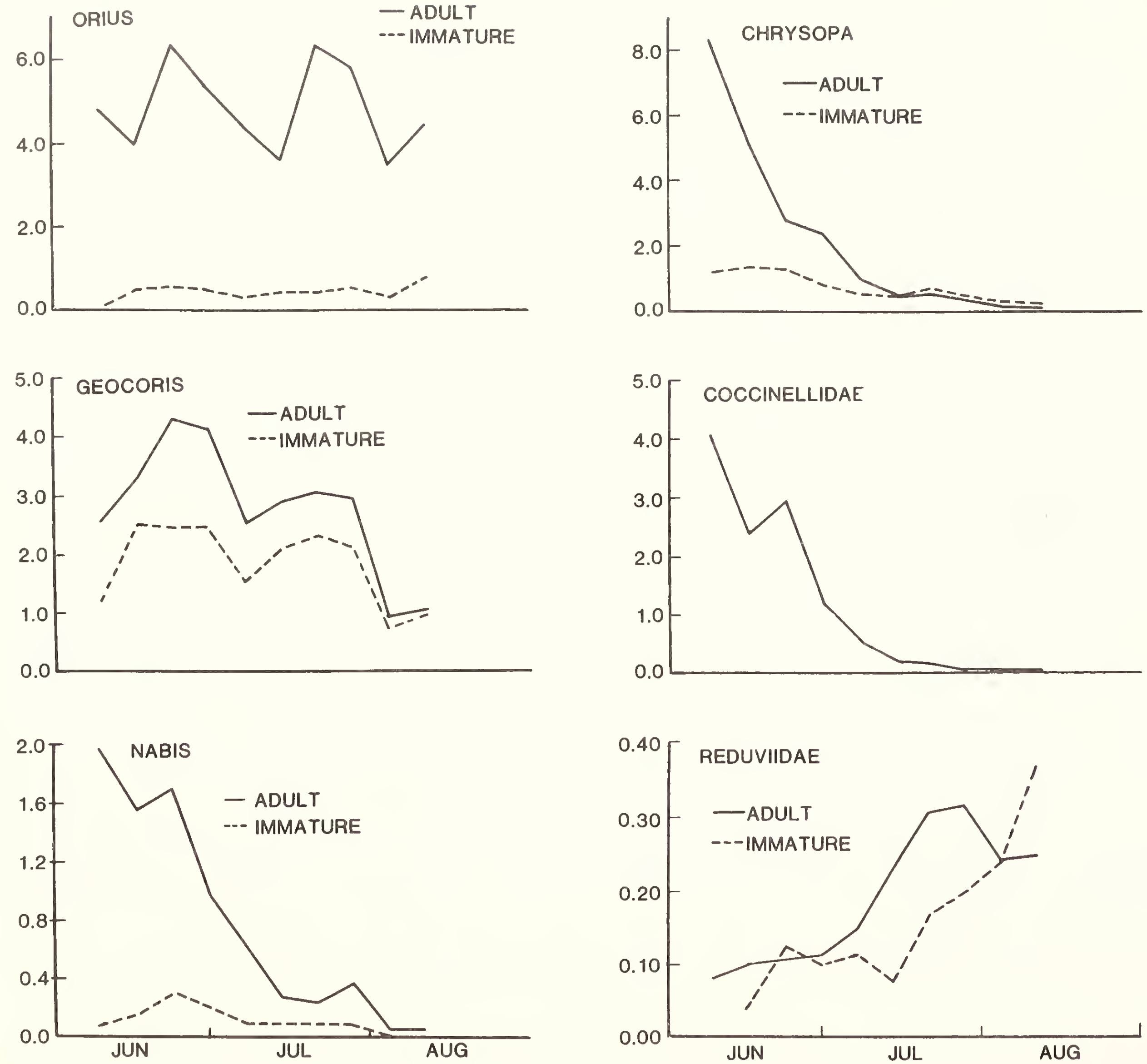
Treatment	Taxon							
	Orius	*Nabis*	*Geocoris*	*Chrysopa*	*Collops*	Coccinellidae	Reduviidae	Spiders
				1982 Experiment[2]				
Disrupt(-)	7.3a	1.6a	7.4a	3.4a	0.3b	2.1a	0.2b	1.7b
Disrupt(+)	5.5b	1.0b	3.7c	1.8b	.1b	.5c	.3ab	2.2ab
NoMate(-)	5.4b	1.0b	5.0b	4.0a	.8a	1.4b	.4a	3.0a
NoMate(+)	2.9c	.7b	5.8b	2.7ab	.1b	.4c	.5a	2.4ab
Insecticides	5.5b	1.1b	5.0b	3.7a	.2b	2.8a	.1b	2.9a
				1983 Experiment[3]				
NoMate(-):								
Pre	1.7	3.2	9.4	5.3	.1	2.5	.2	9.0
Post	6.7	3.5	13.5	5.5	.3	5.5	.1	8.8
NoMate(+):								
Pre	2.7	2.3	6.4	10.7	.3	3.0	.2	8.6
Post	3.2	1.1	11.1	6.8	.2	2.0	.1	6.7

[1]Seasonal average of 6 replications, twice-weekly samples June 8 to July 29, 1982. Samples excluded after any insecticide was applied to a pheromone-treated field or after any nontrichlorfon insecticide was applied in fields treated with insecticides. Averages followed by the same letter are not significantly different according to Duncan's multiple-range test, *P*=0.05.

[2]Seasonal average/100 sweeps.

[3]Seasonal average/200 sweeps. Pretreatment and posttreatment comparisons on a matching date basis. Pretreatment counts were made on the day of treatment; posttreatment counts 48 h later.

PREDATORS PER 100 SWEEPS



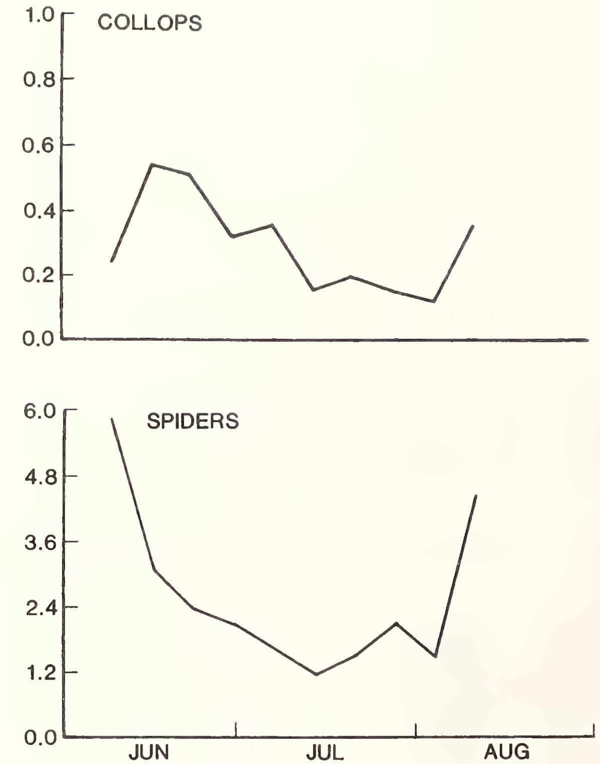


Figure 4.
Average numbers of beneficials per 100 sweeps in 30 fields, without regard to pheromone or insecticide treatments. Twice weekly sweeps (100 per quadrant/field) were averaged for each data point (24,000 sweeps).

through the season. Numbers of *Chrysopa* and Coccinellidae adults were high in June but decreased markedly through July and August, whereas Reduviidae were low in June but increased during July. Numbers of *Collops* collected were low throughout the season, and numbers of spiders were high at the beginning of the season, decreased by about 80 percent in July, but increased in August.

Trap Studies

During the trapping studies, pink bollworm male moth catches in NoMate PBW-treated fields averaged less than 0.2 per trap/night (fig. 5). Average moth catches increased from about 0.1 per trap/night to above 30 after the last Disrupt application. Trap catches increased after the first of August in fields treated with insecticides only, despite the fact that permethrin was being routinely applied.

The average numbers of male moths caught in traps (including all field treatments) baited with Disrupt Lure-Tape or NoMate PBW fiber lure, within fields treated with NoMate PBW, Disrupt, or insecticides were not significantly different, and there was no significant interaction between lure types and treatments (table 5). Significantly fewer male pink bollworm moths were caught in fields treated with NoMate PBW than in fields treated with Disrupt or insecticides. Average numbers of male pink bollworm moths caught in traps baited with 1, 2, or 4 mg (including all field treatments) of gossyplure in Disrupt Lure-Tape or NoMate fiber lures (1.2, 2.3, or 4.6 mg gossyplure) were not significantly different, and there was no significant interaction between lure amount and field treatment (Disrupt, NoMate PBW, or insecticides), but, as in the previous study, fewer moths were caught in fields treated with NoMate PBW than in fields treated with insecticides or Disrupt (table 6).

Figure 6 shows the standard deviations of male moth trap catches plotted against the average log plus one of

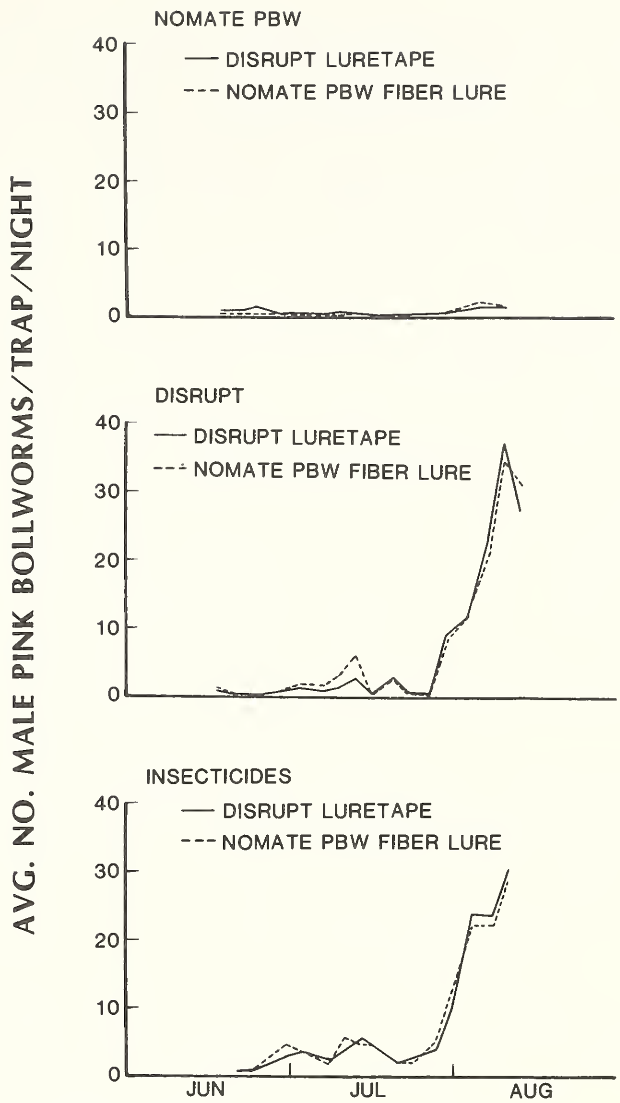


Figure 5.
Average numbers of male pink bollworm moths per trap/night in four fields treated with NoMate PBW, Disrupt, or insecticides only.

male moth trap catches. The data show a positive relationship between standard deviations and average trap catches up to about 1.4 on the log scale. The standard deviation of moth catches above about 1.4 on the log scale (24 in actual numbers of moths) decreased significantly. For the average log (count +1) $\geq$1.4, the standard deviation was 0.108354. The calculated 95-percent confidence intervals are shown in table 7. The data show that when one trap per quadrant/field catches an average of 20 male moths per

Table 5. Average[1] number of male pink bollworm moths caught per trap/night in Delta traps baited with Disrupt LureTape or NoMate PBW fibers and placed in cottonfields treated with insecticides, NoMate PBW, or Disrupt

Cottonfields treated with--	Lure type[2] Disrupt LureTape	NoMate PBW fibers
Insecticides	7.4a	7.5
NoMate PBW	.7b	.5b
Disrupt	7.0a	7.3a
Mean	[3]7.6	[3]5.1

[1]Average of 16 traps for 27 days.

[2]Averages for lure types in different treated fields not followed by the same letter are significantly different according to Duncan's multiple-range test, P=0.05.

[3]No significant difference.

Table 6. Average[1] number of male pink bollworm moths caught per trap/night in Delta traps with 1, 2, or 4 mg gossyplure in Disrupt LureTape or NoMate fiber lures and placed in cottonfields treated with insecticides, NoMate PBW, or Disrupt

Cottonfields treated with--	Lure amount[2] 1/2	Standard	2X
Insecticides	14.27a	15.75a	15.45a
NoMate PBW	3.60b	1.32b	4.17b
Disrupt	13.11a	13.15a	15.28a
Average	[3]10.33	[3]10.07	[3]11.63

[1]Average of 8 traps, 4 baited with Disrupt LureTape and 4 with NoMate PBW fibers, for 14 days.

[2]Averages for lure amount between treated fields not followed by the same letter are significantly different according to Duncan's multiple-range test, P=0.05. See text for milligrams active gossyplure.

[3]No significant differences.

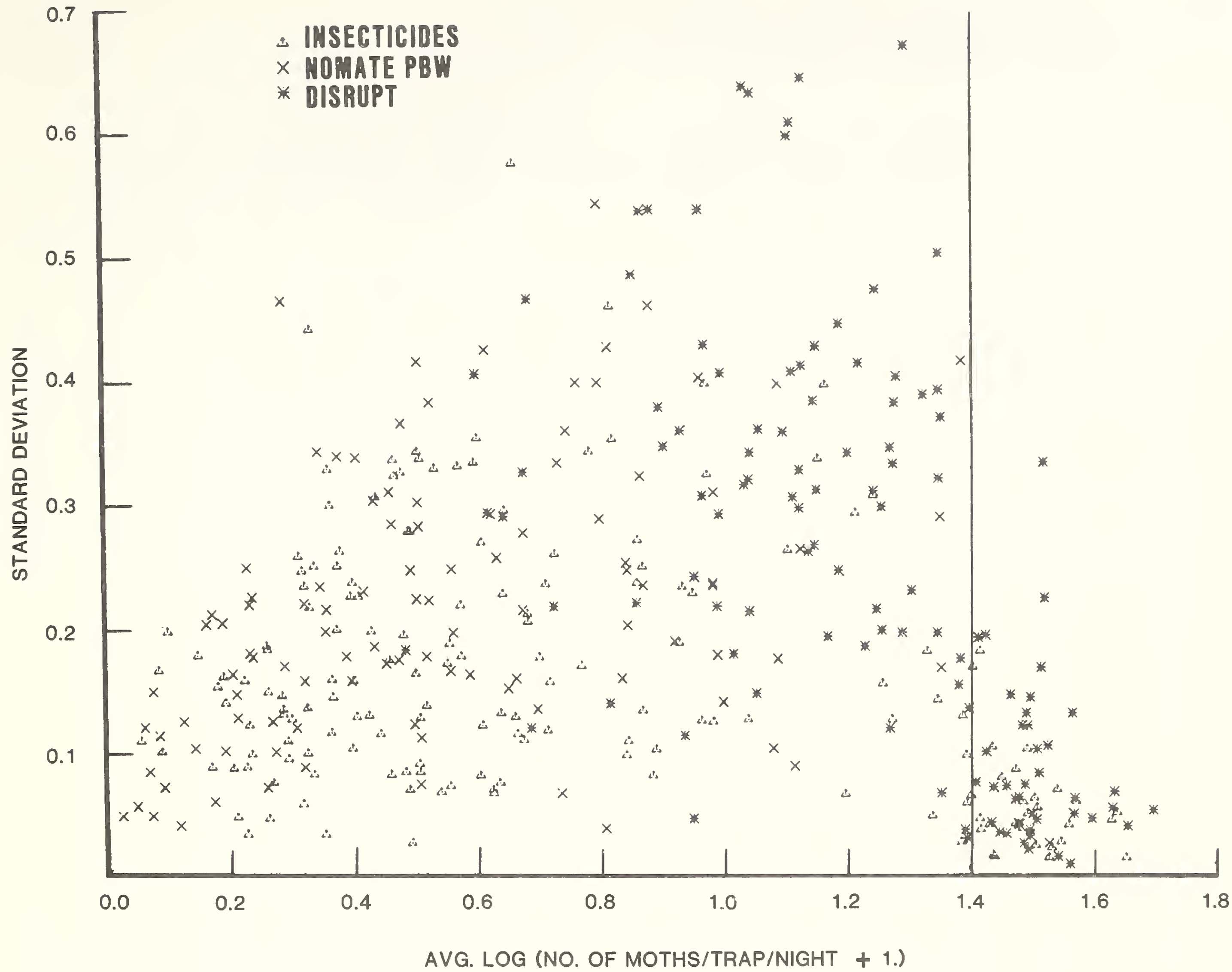


Figure 6.
Gossyplure-baited trap catch standard deviations vs. average log (numbers of male pink bollworm moths per trap/night +1); counts obtained from cottonfields treated with NoMate PBW, Disrupt, or insecticides only between the second week in May and the second week of September 1982.

trap/night, the 95-percent confidence limits range from 10 to 42 (fig. 7). Similar calculations for 1 to 10 traps per field show that the confidence intervals decrease as the number of traps per field increases.

DISCUSSION

Conceptually, mating disruption for pink bollworm control using gossyplure involves sensory adaptation, central nervous system habituation, and confusion (Shorey 1976), the resulting reduction in mating being directly related to decreased reproduction and reduced crop infestation. Staten and Haworth (1981) suggested adding small amounts of a toxicant to the gossyplure-substrate-sticker combination to kill male moths finding the point sources coated with the material. Rates of application with currently available gossyplure carrier systems are determined by adjusting the number of individual fibers or flakes distributed in the field (known amount of gossyplure/point source). Gossyplure

Table 7. Ninety-five percent confidence intervals for number of male pink bollworm moths per trap/night for different numbers of traps per cottonfield

Average[1] male pink bollworm moth catch	Confidence intervals for number of traps (η)[2]-- 10		8		6		4		2		1	
	LO	UP	LO	UP	LO	UP	LO	UP	LO	UP	LO	UP
0.00	0.00	0.22	0.00	0.25	0.00	0.30	0.00	0.38	0.00	0.57	0.00	0.90
1.00	.54	1.59	.50	1.67	.43	1.80	.33	2.01	.12	2.57	.00	3.54
2.00	1.24	3.02	1.16	3.16	1.06	3.38	.89	3.76	.56	4.77	.19	6.56
3.00	1.92	4.49	1.81	4.69	1.66	5.01	1.43	5.59	.97	7.11	.47	9.86
4.00	2.58	5.98	2.44	6.26	2.25	6.70	1.95	7.48	1.37	9.55	.74	13.38
5.00	3.23	7.51	3.06	7.86	2.82	8.41	2.46	9.42	1.75	12.09	.99	17.09
6.00	3.88	9.05	3.67	9.49	3.39	10.16	2.95	11.40	2.12	14.71	1.23	20.95
7.00	4.51	10.61	4.28	11.13	3.95	11.94	3.44	13.41	2.48	17.39	1.46	24.97
8.00	5.14	12.19	4.87	12.79	4.50	13.74	3.92	15.46	2.83	20.14	1.69	29.12
9.00	5.77	13.78	5.46	14.47	5.04	15.56	4.39	17.54	3.18	22.95	1.91	33.38
10.00	6.39	15.38	6.05	16.17	5.58	17.40	4.86	19.65	3.51	25.80	2.12	37.76
11.00	7.00	17.00	6.63	17.88	6.11	19.25	5.32	21.78	3.85	28.71	2.33	42.24
12.00	7.61	18.63	7.20	19.60	6.64	21.13	5.78	23.93	4.18	31.66	2.53	46.82
13.00	8.22	20.26	7.77	21.34	7.16	23.01	6.23	26.11	4.50	34.65	2.73	51.50
14.00	8.82	21.91	8.34	23.09	7.68	24.92	6.68	28.31	4.82	37.67	2.93	56.25
15.00	9.42	23.57	8.91	24.84	8.20	26.83	7.12	30.52	5.13	40.74	3.12	61.09
16.00	10.02	25.23	9.47	26.61	8.71	28.76	7.56	32.75	5.44	43.84	3.31	66.01
17.00	10.61	26.90	10.03	28.39	9.22	30.70	8.00	35.00	5.75	46.98	3.50	71.01
18.00	11.20	28.59	10.58	30.17	9.73	32.65	8.43	37.27	6.06	50.14	3.68	76.08
19.00	11.79	30.27	11.13	31.97	10.23	34.62	8.86	39.55	6.36	53.34	3.87	81.21
20.00	12.38	31.97	11.68	33.77	10.73	36.59	9.29	41.85	6.66	56.57	4.04	86.42
21.00	12.96	33.67	12.23	35.58	11.23	38.57	9.72	44.16	6.96	59.82	4.22	91.68
22.00	13.54	35.38	12.78	37.40	11.73	40.57	10.14	46.48	7.25	63.10	4.40	97.01
23.00	14.12	37.09	13.32	39.22	12.22	42.57	10.56	48.82	7.54	66.41	4.57	102.40
24.00	14.70	38.81	13.86	41.05	12.71	44.58	10.98	51.16	7.83	69.74	4.74	107.85
[3]25.00	21.20	29.44	20.79	30.02	20.21	30.87	19.26	32.37	17.27	36.00	14.79	41.82
30.00	25.47	35.30	24.99	35.98	24.29	37.00	23.15	38.78	20.78	43.13	17.82	50.06
35.00	29.74	41.15	29.18	41.95	28.37	43.13	27.05	45.20	24.30	50.23	20.86	58.29
40.00	34.01	47.01	33.37	47.91	32.44	49.26	30.95	51.62	28.81	57.35	23.89	66.53
45.00	38.29	52.86	37.56	53.87	36.52	55.39	34.84	58.04	31.32	64.46	26.93	74.76
50.00	42.56	58.72	41.75	59.84	40.60	61.52	38.74	64.45	34.84	71.58	29.96	83.00

[1]Confidence intervals for log (count +1) <1.4; s.d=(0.13933)=(0.12844 x average).

[2]LO = lower limit; UP = upper limit.

[3]Confidence intervals for log (count +1) $\geq$1.4 on average count $\geq$25 using a standard deviation of 0.108354.

is permeated in the atmosphere of cottonfields at rates to (1) disrupt moth communication, inhibit male moth orientation, and prevent or reduce mating, and/or (2) provide so many pheromone point sources that male moths are confused or involved in false-trail following, which also results in reduced mating. Affected male moths, in a high percentage of the cases, may not locate the point sources. Thus, other authors have proposed reducing the amount of gossyplure and number of point sources in the crop system to levels that are less effective in communication disruption so the male moth more readily finds the attractive point sources coated with toxicant material.

Many growers and pest-control advisers have added the small amount of toxicant to the gossyplure-sticker combination but have not reduced the number of point sources (gossyplure per hectare). Results of the present study using this

system did not show any difference in male moth catches between NoMate PBW or Disrupt with or without permethrin during the period of pheromone application; however, the amounts of gossyplure active ingredient and the numbers of point sources [(about 2.86 g a.i./ha, 11,856 point sources (fibers) for NoMate PBW, and about 3.71 g a.i./ha, 23,712 point sources (individual 0.3 cm^2 Disrupt pieces), for Disrupt)] may have been too high to effectively function within the male annihilation concept. Both NoMate PBW and Disrupt were highly effective in reducing male moth catches in baited traps within treated fields when used at label-recommended rates (37.1 g product/ha for NoMate PBW and 148.2 g product/ha for Disrupt). Numbers caught were less than 1.0 per trap/night during treatment.

The addition of permethrin to the Disrupt-sticker combination appeared to significantly improve the effectiveness of Disrupt for pink bollworm control, as measured by male moth catches after the period of pheromone application and by reduced crop damage; however, the higher trap catches and greater crop damage recorded in Disrupt(-) fields may have occurred because of greater initial pink bollworm numbers, which never abated in those fields.

Henneberry et al. (1981) reported that 10 applications of Disrupt (3.71 g a.i./ha) applied at first square and then at 14-day intervals reduced pink

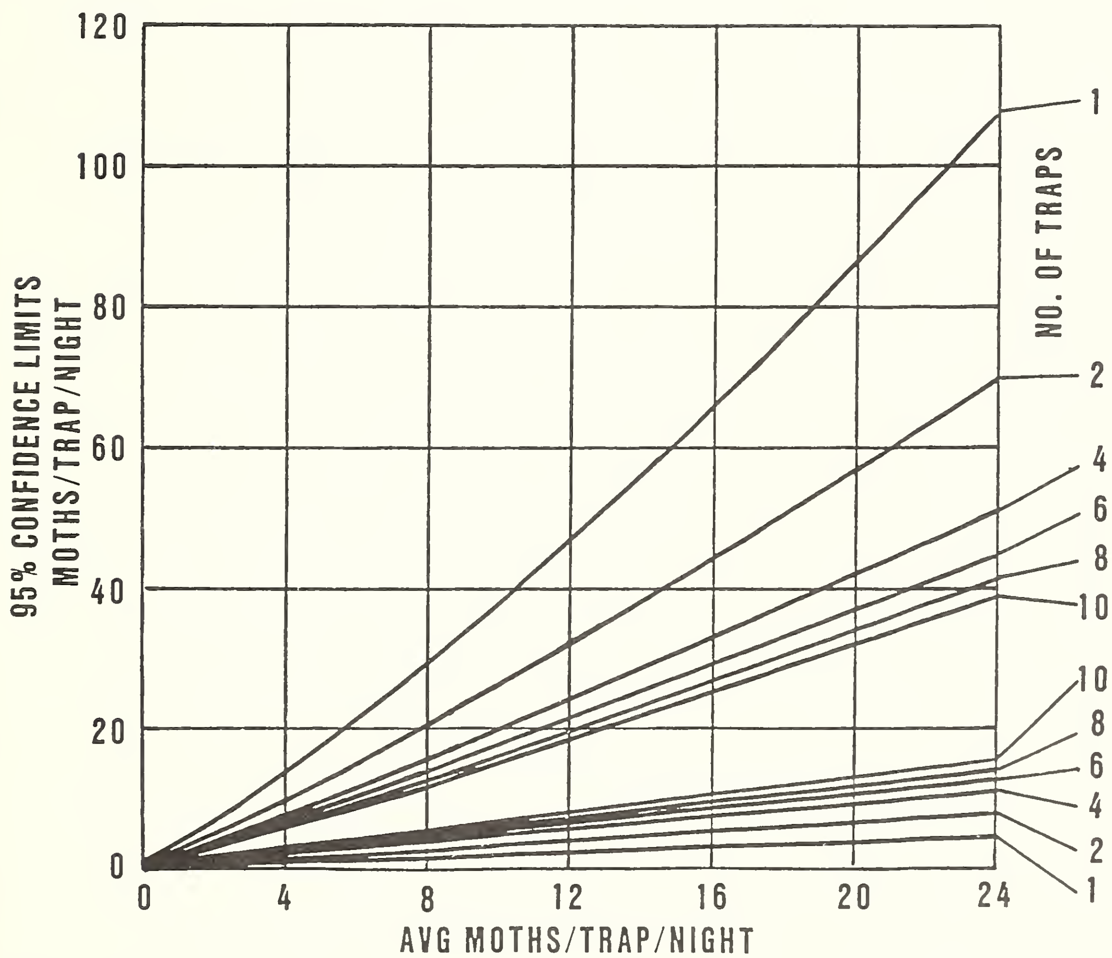


Figure 7.
95 percent confidence limits for average number of pink bollworm male moths caught per trap/night, using from 1 to 20 traps per cottonfield under different moth population densities.

bollworm male moth trap catches (seasonal average 93 percent), boll infestations (seasonal average 68 percent), and pink bollworm female mating (about 50 percent, seasonal average). In those studies, the initial Disrupt applications were made when male moth trap catches in gossyplure-baited traps were less than one per trap/night. Additionally, pink bollworm larval infestations in bolls in control plots did not reach economic levels until early September. Doane and Brooks (1981) reported that the best pink bollworm control with NoMate pink bollworm was obtained when applications to cottonfields were initiated at first square at low pink bollworm population densities.

In the present study, an average of five applications (June 4 to July 24) of Disrupt (3.71 g a.i./ha, with or without permethrin) was made with first application initiated at first flowering (about 21 days after squaring). Male moth catches in gossyplure-baited traps averaged about 4 to 7 per night/trap for 7 days before the first Disrupt applications. Under these higher pink bollworm moth population densities, less effective pink bollworm control was obtained, with resulting seasonal average percentages [Disrupt(+) and Disrupt(-)] of bolls infested reaching 5.6 and 10.8 and average numbers of pink bollworm per 100 bolls reaching 6.1 and 14.6, respectively. Infestations in Disrupt(-)-treated fields increased to economic levels in July. An average of one trichlorfon application per Disrupt(-) field and subsequent commercial insecticide applications on all Disrupt-treated fields failed to reduce or prevent populations in bolls from increasing, which further indicates that very high population levels existed in those fields at the start of the season. Unfortunately, no untreated control fields were available for comparative infestation data.

NoMate PBW, with and without permethrin, applied to fields with lower pink bollworm population densities gave control equal to that obtained with insecticides. However, an average of one trichlorfon application was also made on all fields during the times NoMate PBW applications were being made.

Timing of the initiation of gossyplure applications, frequency of subsequent applications, rate of application, and performance at low and high pink bollworm population densities are critical considerations in the use of gossyplure for pink bollworm control in cottonfields. At present, inadequate information is available about these areas of concern. Additional studies need to be conducted under controlled experimental conditions to define the role of gossyplure as an integrated pest management component for behavioral control of pink bollworm in cotton production systems.

Our results indicate that the addition of permethrin to NoMate PBW and Disrupt resulted in reductions in the seasonal average of six of eight beneficial predators sampled (*Orius*, *Geocoris*, *Nabis*, *Chrysopa*, *Collops*, and Coccinellidae). We suspect that the greater reduction in beneficial predators observed in the Disrupt-treated fields as compared with the NoMate PBW-treated fields may be due to the greater number of point sources in the former. The effects of these beneficial insect reductions on the regulation of pest populations in the insect complex is unknown. However, Van Steenwyk et al. (1975) observed significant increases in the mean density of *Heliothis* spp. associated with increased insecticide use in cottonfields, causing 63 to 73 percent reductions of the same beneficial insect predator complex.

The benefits of adding permethrin to either NoMate PBW or Disrupt for pink bollworm control need to be weighed against the possible adverse effect on beneficial predators shown in the present study. Additional studies need to be conducted to verify these results since Butler and Las (1983) report that permethrin added to NoMate PBW had minimal or no effect, with the possible exception of *Hippodamia* spp., on beneficial predators in their studies.

The difference in results is difficult to explain but may have occurred as a consequence of different sampling procedures and other methods used. In any event, the reductions in predator populations in the pheromone plus permethrin-treated fields in our studies were considerably smaller than occur in fields treated with insecticides, as reported by Butler and Las (1983).

Results from studies reported here showed no significant differences in the average number of male pink bollworm moths caught per trap/night, regardless of (1) the amount of lure used (within the range of one to four mg gossyplure) in either type of bait (NoMate PBW fibers or Disrupt LureTape) and (2) whether (a) Disrupt LureTapes were used in NoMate PBW-treated fields, (b) NoMate fiber lures were used in Disrupt-treated fields, or (c) either lure type was used in fields treated with insecticides only.

More important than available lure type and amount seems to be the consideration of numbers of traps per field and frequency of changing traps (Foster et al. 1977). Establishment of confidence limits for trap catches in relation to trap numbers per field provides a basis for the specific number of traps to estimate the true number of male pink bollworm moths that will be caught using the Delta trap. The minimum of four traps per field provided a reasonable estimate of the true value. Results with fewer than four traps per field were extremely variable. The results also showed that standard deviations of male moth trap catches decreased when the average numbers of moths caught increased above about 25 per trap/night and corroborate the results of Lingren et al. (1980) regarding the loss of efficiency of the Delta trap under high moth population densities. Thus, it seems that Delta traps reach an upper limit of efficiency at about 25 male moths per trap/night, despite the fact that single traps can catch well in excess of 100 moths in one night.

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